Chapter 7. Technology Roadmap: Cycles of Matter and Energy

The SEU science program in the area of Cycles of Matter and Energy will encompass measurements across the entire electromagnetic spectrum, from radio waves gamma rays, as well as measurements of other forms of cosmic radiation: cosmic rays, dark matter, and gravitational waves. Improvements in sensitivity, spectral and spatial resolution, and collecting area are needed. This will require vigorous technology development. In their earliest stages of concept development, new space technologies will be pursued through the R&A programs. NASA's SBIR (Small Business Innovative Research Program) provides another vital yearly addition to SEU technology development. However, technologies developed in both of these programs will eventually require detailed engineering studies. From that point on, future SEU missions cannot succeed without the focused and stable funding of a dedicated technology program.

Highlighted below are the technologies required for SEU missions that are currently envisioned. These encompass optics, detectors, and spacecraft systems.

Large, Lightweight Optics

Continuing exploration of the Universe will require bigger and better space telescopes at all wavelengths. Robust large-aperture lightweight optical systems must be developed if launching is to be feasible and affordable. Ways must be found to increase apertures, reduce density, lower operating temperatures, and improve surface quality, through programs that are rapid and cost effective.

Stiffer materials would permit larger apertures with lower areal densities. Low and uniform coefficients of thermal expansion will simplify cryogenic operation. Stress-free deposition and curing would enable low-cost mass production.

Fabrication poses many challenges, from the logistics of handling large and fragile optical components to the treatments required to obtain the desired surface quality and the development of cryogenically cooled optics. Research must investigate a broad range of techniques for grinding, polishing, and forming. Means for characterizing optical performance and in-space contamination, both by measurement and analysis, are essential. As optics become larger and lighter, adequate ground testing may no longer be feasible. Analytical modeling will be crucial to the success of such missions.

"Equipped with his five senses, man explores the Universe around him and calls the adventure science."
—Edwin P Hubble

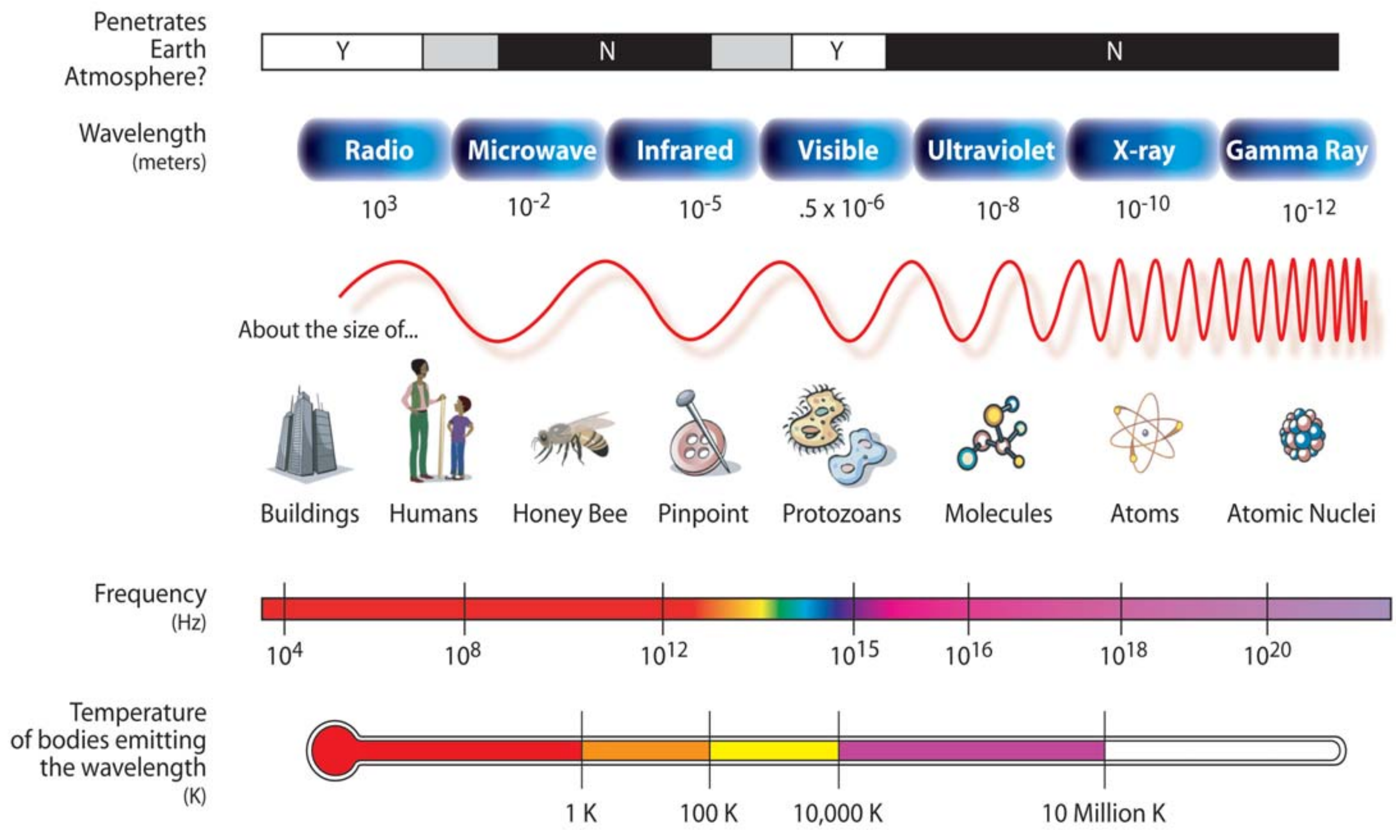
Detectors

Detector technologies in all electromagnetic wavebands have advanced dramatically in recent years, enabling most of the SEU missions currently flying or nearing launch. A detector is characterized by its quantum efficiency, its spectral bandpass, and in some cases its intrinsic spatial and spectral resolution. Ancillary technologies include readout electronics, digital processors, and cooling systems. The demands of upcoming missions will require major advances in all of these areas. NASA support is particularly urgent for detector technologies without strong commercial or military research and development programs. A few examples are detailed below:

Radio Interferometry

Space-based (or space-to-ground) radio interferometry requires improved sensitivity, particularly at the shorter wavelengths. High-priority technologies include large space-based

THE ELECTROMAGNETIC SPECTRUM



apertures with submillimeter surface accuracy, wide-bandwidth communications from space to ground, and cooling for receivers in space. Since optimum imaging for space-ground baselines requires highly elliptical orbits that pass through Earth's radiation belts, robust materials and electronics for a high-radiation environment are essential. Correlation of high bandwidth signals will also demand precise orbit determination.

Submillimeter/Far Infrared

Cooled space-borne telecopes will permit huge sensitivity gains at these wavelengths, but these will be wasted without large format detector arrays. Direct detectors and heterodyne instruments are needed. The direct detectors need architectures and readout electronics that will scale to large arrays, and greatly improved sensitivity if they are to be used for spectroscopy. Heterodyne systems need more stable oscillators and quieter electronics, especially at the highest frequencies.

Near Infrared/Optical

Imaging detectors based on charge coupled devices (CCDs) and low bandgap array detectors have been available for a number of years. Future missions demand extremely large (billion-pixel) arrays, posing new challenges in production yield, detector uniformity, detector packaging, high-speed readout, and on-board data storage. Improvements in readout noise, quantum efficiency, spectral coverage, charge transfer efficiency, and radiation hardness will also be required.

Ultraviolet

Significant improvements in ultraviolet detector sensitivity are needed. Photocathode-based photon counters permit high counting rates and good background rejection but suffer from low quantum efficiency. UV-sensitive CCDs have higher quantum efficiency, but read noise is too high for faint source spectroscopy. So-called 3-D energy-resolving detectors offer tremendous promise, but much larger arrays must be developed.

X Ray

At X-ray energies, cryogenic detectors have revolutionized the field in recent years. Thirty-by-thirty arrays of microcalorimeters are envisioned for Constellation-X, but such small arrays have very limited fields of view. Future missions will need much larger arrays.

Gamma Ray

Gamma-ray astronomy can progress through development of an advanced Compton telescope for the study of nuclear lines and continuum emission at MeV energies. The science goals require 25–100 times the sensitivity of CGRO and INTEGRAL. This will demand major improvements in angular resolution, detector area and field of view, and background rejection. Advances in electronics, detector cooling, and event processing are also required.

Cosmic Rays

Future cosmic-ray research will require large-area million-channel particle detectors. These require low power acquisition electronics, intelligent data compression systems, and fast computing. Space-based observations of cosmic-ray showers via air fluorescence will require fast million-pixel, wide-field light detectors.

Spacecraft Systems

Continued advances in spacecraft technologies are crucial to SEU science goals. Several of the envisioned missions incorporate interferometric systems on multiple spacecraft that need precision pointing and/or formation flying systems. Thermal and mechanical stability tolerances are very tight, so new materials and mechanical designs must be studied. Requirements on the accuracy of positioning and pointing are beyond the state of the art. Advanced inertial reference systems may be required. Micronewton thrusters, currently under development for LISA, require further study for adaptation to other missions.

The sensitivity goals of several envisioned missions require new cryogenic technology, in both active and passive cooling. This is especially true in the submillimeter and far infrared bands, where all the optics must be cooled, including the primary mirror. And we must not forget the hostility of a cryogenic space environment to simple yet critical devices: hinges, latches, and actuators.